

# POWER ELECTRONICS AND MACHINE CHALLENGES AND OPPORTUNITIES

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The development of power electronics and electric machinery presents significant challenges to the advancement of electric and hybrid vehicles. A whole new class of electronic technologies is expected to emerge, spurred by the development of electric drive vehicles. Electronic components and systems development for vehicle applications have progressed from the replacement of mechanical systems to the availability of features that can only be realized through interacting electronic controls and devices. Near-term applications of power electronics in vehicles will enable integrated powertrain controls, integrated chassis system controls, and navigation and communications systems. Future application of optimized electric machinery will enable highly efficient and lightweight systems.

Research and development is required in the following areas to ensure the continued development of power electronics and electric machines to meet the rigorous demands of automotive applications:

Materials and Manufacturing Technologies: Manufacturing equipment and processes are needed to make advanced technology vehicles cost competitive in high volume markets. Cost effective materials and processes are needed to meet unique automotive environmental demands.

Power Generation Systems: New generation technologies like turbines or fuel cells need to interface with the vehicle's power and control system to cleanly and efficiently respond to power system load requirements. Energy storage systems need to efficiently interface with the power system.

Propulsion Drive Motors: Improved motor magnetics are needed to reduce cost and weight of the traction system. New designs and control methods are required to broaden the range at which the propulsion motor operates at its highest efficiency, for varying load conditions typical of automotive drive cycles.

Accessory Drives: Subsystem accessories require small, light-weight, efficient motors to replace analogous belt or vacuum driven subsystems.

Power Electronic Controls: Interfacing components, including wiring, switches, and transformers, for power management and distribution account for a large fraction of electronic losses; as well as substantially contributing to the weight and cost of the overall system.

The principle challenge in all of these areas is affordability; then come robustness and performance, primarily as efficiency and driver acceptance. The following chart shows the technical targets for PNGV as outlined in 1995 with some recent updates.

**Technical Targets for  
Power Electronics and Electrical Machines**

| Parameter                                                       | Units | 1997 | 1998 | 2000 | 2002 | 2004 | 2006 |
|-----------------------------------------------------------------|-------|------|------|------|------|------|------|
| <b>System: (based on simulation results for the data below)</b> |       |      |      |      |      |      |      |
| Driveline Efficiency                                            | %     | 75   | 78   | 80   | 82   | 85   | 86   |
| Regeneration Efficiency                                         | %     | 60   | 68   | 75   | 77   | 80   | 82   |
| Weight (w/o engine or energy storage)                           | kg    | 140  | 115  | 85   | 70   | 60   | 55   |
| <b>Electric Motor:</b>                                          |       |      |      |      |      |      |      |
| Specific Power at Peak Load                                     | kW/kg | 1.2  | 1.5  | 2.0  | 2.5  | 3.0  | 3.0  |
| Cost                                                            | \$/kW | 10   | 10   | 6    | 5    | 4    | 3    |
| Efficiency (10% to 100% speed, FTP cycle)                       | %     | 90   | 90   | 92   | 94   | 95   | 96   |
| <b>Power Electronics System (Inverter/Controller):</b>          |       |      |      |      |      |      |      |
| Specific Power at Peak Load                                     | kW/kg | 10   | 12   | 15   | 20   | 25   | 25   |
| Cost                                                            | \$/kW | 50   | 10   | 5    | 4    | 2    | 2    |
| Efficiency (10% to 100% speed, FTP cycle)                       | %     | 94   | 95   | 97   | 97   | 98   | 98   |

**Power Electronics**

Power electronics enabling technologies must be developed that will dramatically reduce the cost and the weight of electric propulsion system technologies and high-power accessories. A high degree of functional integration must be added while maintaining high efficiency and reliability for automotive industry applications.

Power electronics must be provided for the HEV for power system control management, bi-directional traction drive, power generation dc-dc converters, and auxiliary motor drives (e.g., HVAC, power steering, suspension, energy storage sub-systems, engine valves operation, etc.). Specifically, the challenges are to reduce cost, reduce weight and volume, improve efficiency, and improve packaging.

### Power Electronics Challenges:

- a. Materials technology is inadequate for cost effective production of power electronics and electric machines for automotive applications.

Processing, characterization, and optimization of components for high temperature operation, including materials with wider band gaps and devices with higher power densities are needed. For example, power electronic components are not sufficiently resistant to RF interference to meet regulatory demands and recently developed lead-free solders are not adequate for temperatures above 150°C. Automotive environments reach temperatures between -40°C and 150°C, but commercially available power electronic component packaging is only rated for operation up to 120°C. Packaging accounts for 70% of the cost of silicon devices, capacitors, sensors, and inductors. Current packaging is bulky, and generally designed for fixed-location, low moisture, low EMI, and ambient temperature environments.

- b. Current thermal management techniques are inadequate for high power density microsystems.

High power density concentrates heat generation. New technologies are needed to dissipate the heat and to ultimately remove it from the module to meet reliability requirements for 150,000 miles.

- c. Power electronic components are not adequately miniaturized or optimized.

Current power electronic technology is bulky and heavy. For example, off-the-shelf 100-kW system controllers are about as big as a large hard suitcase and weigh nearly 70 lb. State-of-the-art technologies weigh about 50 lb. per cubic ft. This translates to less than 5 kW/lb. Materials for electronics have not been optimized for cost, volume, and weight. Each power device needs an isolated power supply for its control which multiplies system complexity and cost. Integration of these components is needed to reduce cost, size, and weight. The development of miniaturized ultra-capacitors would contribute considerably to the size reduction of power converters.

### **Electric Machines**

As for power electronics, electric machines must be provided for the HEV for bi-directional traction drive, power generation, and auxiliary motor drives (e.g., HVAC, power steering, suspension, energy storage sub-systems, engine valves operation, etc.). Advanced electric motor materials and manufacturing technologies must be developed that will enable significant reductions in cost and weight for propulsion, auxiliary, and flywheel motors. Revolutionary technologies are needed to enable major efficiency increases while maintaining reliability and durability. Presently, development appears to be focused on induction motors, but efficiency, power density, and cost optimization encourage development of switched reluctance and permanent magnet technologies. There may be new revolutionary designs that help meet the needs of HEV, such as higher voltage (40 V) homopolar motors or ultrasonic motors. Specifically, the challenges are to improve efficiency, reduce weight, reduce cost, and improve performance.

### Electric Machines Challenges:

- a. Electric motor production costs are too high for automotive applications.

New materials and processing technologies are needed to reduce cost. Low cost rotors with high conductance are needed, e.g., die cast copper rotor bars. Low cost, high flux motor cores would reduce manufacturing costs. Switched reluctance motors are less expensive and inherently more robust, but certain performance problems must first be resolved.

- b. High-performance materials cost too much.

Current magnetic core materials (high- and low-silicon steels) perform marginally and costs are too high. New materials or new processes are needed to reduce cost. Permanent magnet materials, used for high-performance components, also need manufacturing refinements to reduce cost. Metal matrix composites for high thermal conductivity would be useful. New winding insulation materials are needed to withstand the automotive operating environment and the high dv/dt introduced by new inverter technologies.

- c. Electric motor attributes and control are inadequate.

Further research to reduce torque ripple, reduce electromagnetic interference, optimize power transfer, reduce or compensate for audible noise, and help lower control cost is needed.

### **Conclusion**

The one parameter of greatest concern in automotive power electronics and electric machinery is cost. While the requirements of performance, efficiency (range), weight, and size must be met to some degree, the overriding concern is cost. The HEV must be affordable for the average consumer or DOE's goal of reducing our dependence on imported petroleum will not be realized. R&D in advanced materials development, manufacturing techniques, and value engineering, as well as new technologies in power converter and electric machinery can meet these requirements. However, all of these advances must work in concert to meet the system needs of motion control.